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Dr. Hui Hu and Dr. Paul Durbin

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Department of Aerospace Engineering
Iowa State University
2271 Howe Hall, Room 1200
Ames, Iowa 50011-2271

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14. ABSTRACT

1). On wind tunnel experiments: We have already conducted extensive wind tunnel experiments to evaluate the effects of wind tunnel testing factors on the behavior of wing-tip vortex structures. A high-resolution stereoscopic PIV system was used to achieve detailed flow field measurements to quantify the transient behavior of the wing-tip vortex structures at different test conductions

2). On CFD simulation: We have already conducted a comprehensive numerical study, which including grid generation and refinement, CFD code modification / development, turbulence model comparison/modification, tailored for the simulation of wingtip vortex flows with and without wind tunnel wall interaction. We have also compared the numerical results with the Stereoscopic PIV measurement results obtained through the wind tunnel experiments.

3). On theoretical analysis: We have conducted an theoretical analysis based the measurements and numerical simulation results to establish the theoretical framework in order to develop a general procedure for wind tunnel testing data correction.

15. SUBJECT TERMS
Wing-tip vortex, wind tunnel testing

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Final Report of AFOSR Funded Research Project:

On the Simulation of Free Flight Vortices in Ground Test Facilities

Submitted by:

Dr. Hui Hu (PI) and Dr. Paul A. Durbin (Co-PI)
Department of Aerospace Engineering
Iowa State University
2271 Howe Hall - Room 1200, Ames, IA 50011-2271
Email: huhui@iastate.edu and durbin@iastate.edu
Tel: 515 294-0094 (Hu) / Tel: 515-294-7234 (Durbin)

Award # FA9550-08-1-0294

Points of Contact:
- Dr. Joycelyn Harrison of AFOSR
- Mr. Scott Waltermire of AEDC

March 29, 2012

1. Objectives: List the objectives of the research effort or the statement of work:

The objectives of this project is to assess the effects of significant wind tunnel testing factors, such as test model blockage, vortex strength, inlet flow non-uniformities and inlet turbulence levels, on the near field behavior of strong wing-tip vortex structures through an integrated experimental, numerical and theoretical study. A primary motive is to assess the need for comprehensive corrections of wind tunnel testing data to simulate free flight conditions. The proposed research aims to shed light on how the wind tunnel environment affects measurements when coherent vortices are present, and how to make corrections to account for discrepancies between the wind tunnel and free flight test environments in flows with strong vortex structures.

Specifically,1). Systematic wind tunnel experiments will be conducted to examine the effects of the wind tunnel confinement on the dynamics of the initial rollup and subsequent development of wing-tip vortices in the near field. 2). Sophisticated, yet practical Computational Fluid Dynamics (CFD) simulations will be coordinated with the wind tunnel testing to provide assistance in experimental design, to identify critical measurement locations, to generate free-flight solutions for comparison, and to assess which are critical to simulating free flight conditions. 3). A theoretical analysis will be attempted with the aim of developing a procedure to correct wind tunnel testing data. It will be based on the experimental data and numerical simulations. The outcomes of this proposed research are expected to provide guidelines and general ideas about correcting wind tunnel test data to account for discrepancies between tunnel and free flight environments when vortex structures are a dominant part of the flow field.

2. Status of effort: A brief statement of progress towards achieving the research objectives.

We have made following progresses on the proposed research:

1). On wind tunnel experiments: We have already conducted extensive wind tunnel experiments to evaluate the effects of wind tunnel testing factors on the behavior of wing-tip vortex structures. A high-resolution stereoscopic PIV system was used to achieve detailed flow field measurements to quantify the transient behavior of the wing-tip vortex structures at different test conductions

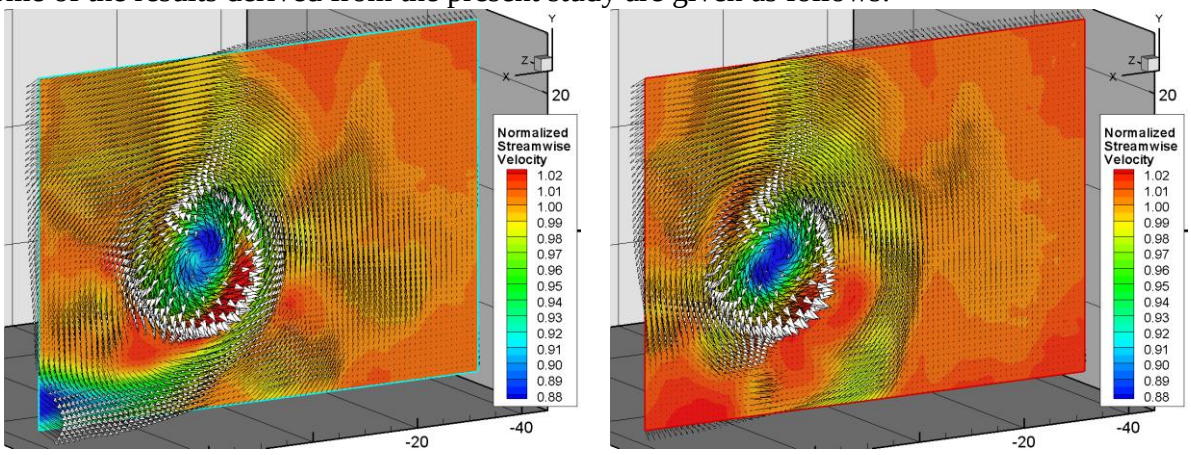
2). On CFD simulation: We have already conducted a comprehensive numerical study, which including grid generation and refinement, CFD code modification / development, turbulence model comparison/modification, tailored for the simulation of wingtip vortex flows with and without wind tunnel wall interaction. We have also compared the numerical results with the Stereoscopic PIV measurement results obtained through the wind tunnel experiments.

3). On theoretical analysis: We have conducted an theoretical analysis based the measurements and numerical simulation results to establish the theoretical framework in order to develop a general procedure for wind tunnel testing data correction.

3. Accomplishments/New Findings:

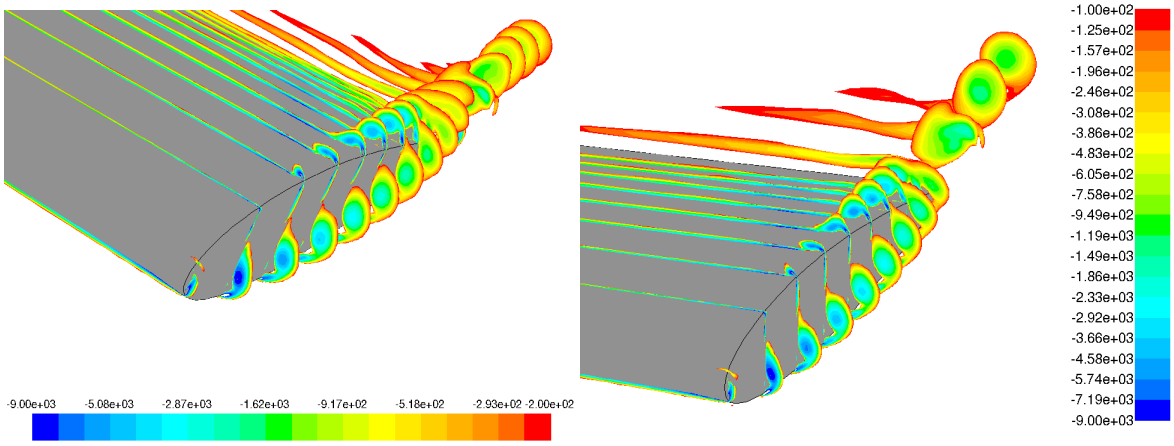
As we planned, we have conducted extensive wind tunnel experiments and CFD simulations to effects of wind tunnel testing factors on the behavior of wing-tip vortex structures. We have also analyzed the experimental and simulation results in order to develop a general procedure for wind tunnel testing data corrections. The new findings derived from this research project are very helpful to elucidate the underlying physics to shed more light on how the wind tunnel environment affects measurement results when strong coherent vortices are present, and how to

make corrections to account for discrepancies between the wind tunnel and free flight test environments in flows with strong vortex structures.
Some of the results derived from the present study are given as follows:



(a). 1.0 chord length downstream (b). 4.0 chord length downstream

Fig. 1: Typical Stereoscopic PIV measurement results to reveal the evolution of the wingtip vortex in the near field.



(a). Wind tunnel test condition (b). Free flight conditions

Fig. 2: Comparison of CFD simulation results of wing-tip vortex structures in wind tunnel testing and free flight conditions

4. Personnel Supported:

Following professional personnel have been working on this research project:

- Dr. Hui Hu, PI, in charge of overall project management and supervise graduate students and post-docs to conduct the experimental part of the proposed research.
- Dr. Paul Durbin, Co-PI, in charge of CFD numerical simulation part of the proposed research, and supervise graduate students to conduct CFD numerical simulations and theoretical analysis.
- Dr. Hongwei Ma, postdoctoral research associate, wind tunnel experiments and data analysis.

- Ms. Xin Huang, Ph.D. student, CFD numerical simulations
- Mr. Hirofumi Igarashi, Master student, stereoscopic PIV measurements
- Mr. Anand Gopa Kumar, Master student, wind tunnel testing.

5. Journal Publications:

- H. Igarashi, H. Ma, P. Durbin and H. Hu, "A Experimental Investigation on the Study on Near-field Wingtip Vortex by using Stereoscopic PIV technique", to be submitted to *AIAA Journal*, 2012.

6. Interactions/Transitions:

a. Participation/presentations at meetings, conferences, seminars, etc.

Invited talks and Seminars

- H. Hu, "Applications of Advanced Flow Diagnostic Technique to Wind Engineering Problems", Invited Speaker, *International Workshop on Wind Engineering Research and Practice Current State-of-the-Art and Future Needs/Plans/Policies.* 05/28/2010~05/29/2010, Chapel Hill, North Carolina, USA. (Prof. P. Sarkar as the Chair of the Workshop).
- H. Hu, "Bio-inspired Aerodynamic Designs for Micro-Air-Vehicle Applications", Department of Mechanical and Material Engineering, Wright State University 09/22/2009. (Prof. H. Dong as the host).
- H. Hu, "Advanced Flow Diagnostic Techniques and Applications to Study Complex Thermo fluid Phenomena", Goodrich Engine Components Division, 08/21/2009. (Dr. B. Williams as the host).

Conference presentations:

- H. Igarashi, H. Ma, P. Durbin and H. Hu, "A Stereoscopic PIV Study of Near-field Wingtip Vortex", AIAA-2010-1029, 48th Aerospace Sciences Meeting and Exhibit, Orlando, Florida, 5- 8 Jan., 2010.
- X. Huang, H. Igarashi, P. Durbin and H. Hu, "Numerical and Experimental studies of Wingtip Vortex in the Near Field". AIAA-2010-0325, 48th Aerospace Sciences Meeting and Exhibit, Orlando, Florida, 5- 8 Jan., 2010.
- H. Igarashi, Durbin and H. Hu, "Effects of Wind Tunnel Wall on the behavior of the Wingtip Vortex in near field", submitted to 49th Aerospace Sciences Meeting and Exhibit, Orlando, Florida, 5- 8 Jan., 2011.

b. Consultative and advisory functions to other laboratories and agencies

None

c. Technology Assists, Transitions, and Transfers.

None

7. New discoveries, inventions, or patent disclosures.

None

8. Honors/Awards:

- Hui Hu (PI): 2009 *Best Paper Award*, AIAA Applied Aerodynamics Technical Committee, 2009.
- Paul Durbin (Co-PI): Fellow of American Physical Society